Radar Reconnaissance of Near-Earth Asteroids

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Groundbased radar observations of NEAs can help identify space resources with commercial potential and can dramatically reduce the cost and risk of the initial spacecraft missions to those objects. The near-Earth asteroid (NEA) population is thought to contain ~1500 objects as large as a kilometer, ~300,000 as large as 100 meters, and more than 100,000,000 as large as 10 meters. More than 10% of the NEAs are more accessible in terms of mission delta-V (i.e., fuel required) than the Moon, Mars, or the moons of Mars. Fewer than 1000 NEAs have been found, but the discovery rate is increasing rapidly. Once an asteroid is discovered (necessarily by wide-field optical telescopes), radar can provide otherwise unavailable information about its size, shape, spin state, and surface properties if it approaches within the range of the Goldstone (California) or Arecibo (Puerto Rico) radar telescopes.

Asteroids generally appear as unresolved points through groundbased optical telescopes, but radar measurements of the distribution of echo power in time delay (range) and Doppler frequency (radial velocity) can yield images with resolution as fine as a decameter. Image sequences that furnish adequate orientational coverage can be inverted to construct geologically detailed 3-D models, to define the rotation state precisely, and to constrain the object's internal density distribution. Estimates of radar scattering properties characterize the surface's cm-to-m-scale roughness as well as its bulk density, which for asteroids depends primarily on porosity and metal concentration. A useful spin-off of radar detection is orbit refinement that simplifies navigation of flyby and rendezvous spacecraft.

The existence of accurate physical models for small NEAs permits realistic modeling of the close-orbit dynamics of robotic or piloted spacecraft. Maneuvering spacecraft in the vicinity of irregularly shaped, small asteroids is extremely challenging, and orbit geometry and stability depend strongly on object shape and spin state.

Radar detections of 55 NEAs (http://echo.jpl.nasa.gov/asteroids/index.html) have established the extreme diversity of the population and have revealed several objects in detail. Radar reflectivities span an order of magnitude, with the highest indicating a nearly entirely metallic composition for (asteroid 1986 DA) and the lowest indicating very low-density material (e.g., 1986 JK). Asteroid surface roughness ranges from negligible (1986 DA) to extreme (e.g., 1992 QN); see http://echo.jpl.nasa.gov/~lance/asteroid_radar_properties/nea.sc_oc.html. Spin periods range from 11 minutes to more than a week, and shapes range from very regular to grotesque. Geographos is more than twice as elongated as any other NEA that has been spatially resolved. Castalia and Bacchus are bifurcated, 1982 TA has a triangular pole-on shape, and Golevka is the most angular object imaged so far. 1998 ML14 is spheroidal, with protrusions that suggest a rock-pile configuration. High resolution images of Toutatis reveal a geologically complex, heavily cratered object in a slow, non-principal-axis spin state. Toutatis' internal density distribution appears to be uniform; the surface's centimeter-to-decimeter-scale roughness also is uniform and is consistent with at least 1/3 of the area being covered by small rocks. Numerous craters are visible on the best-resolved objects, but many other topographic depressions and constructs also are evident. The population apparently includes monolithic objects as well as unconsolidated rubble piles, but in most cases it is impossible to distinguish them from remote images.

Radar and optical observations recently revealed the physical characteristics of 1998 KY26, an approximately 30-meter-wide, monolithic spheroid that is an order of magnitude smaller than any other solar system object ever studied in detail and that rotates an order of magnitude faster than any other solar system body (Ostro et al. 1999, Science 285, 557-559). 1998 KY26 is more accessible to spacecraft rendezvous and roundtrip missions than any other asteroid with a well known orbit. It appears to be mineralogically similar to carbonaceous chondrites, the most primitive and volatile-rich meteorites. This object's mass may be 10 to 20% chemically bound water, making it a fine candidate for resource exploitation.